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Prospects for indirect luminosity measurements at LHCb

Anderson, J

Abstract: We summarise the prospects for indirect luminosity measurements at LHCb. Two candidate processes have been identified for such measurements: electroweak boson production and elastic dimuon production via two photon fusion. The cross-section for W and Z production at LHCb has been calculated at NNLO with an uncertainty of 4

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Conference or Workshop Item

Accepted Version

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Prospects for indirect luminosity measurements at LHCb

Jonathan Anderson, Universität Zuerich
For the LHCb collaboration

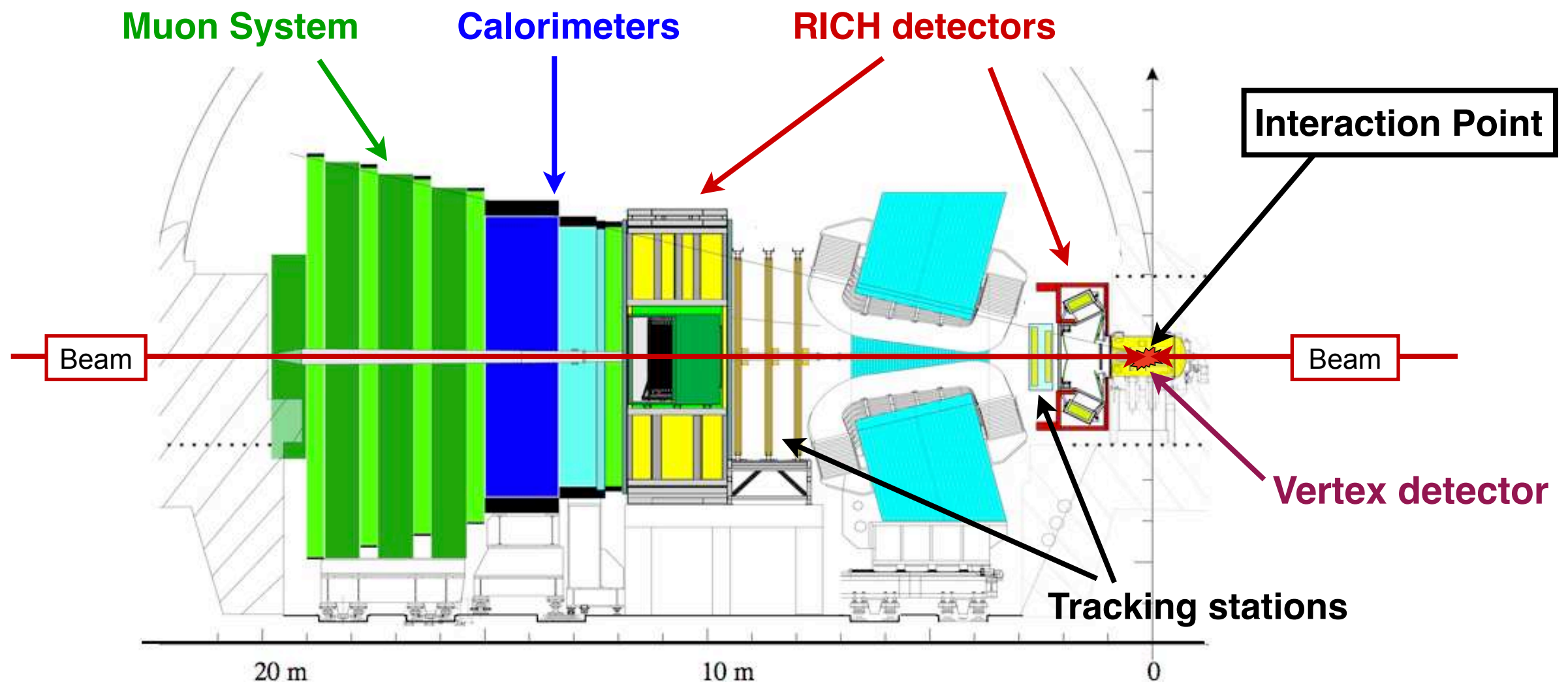
LHCb: A **forward** spectrometer

Fully instrumented at high rapidities

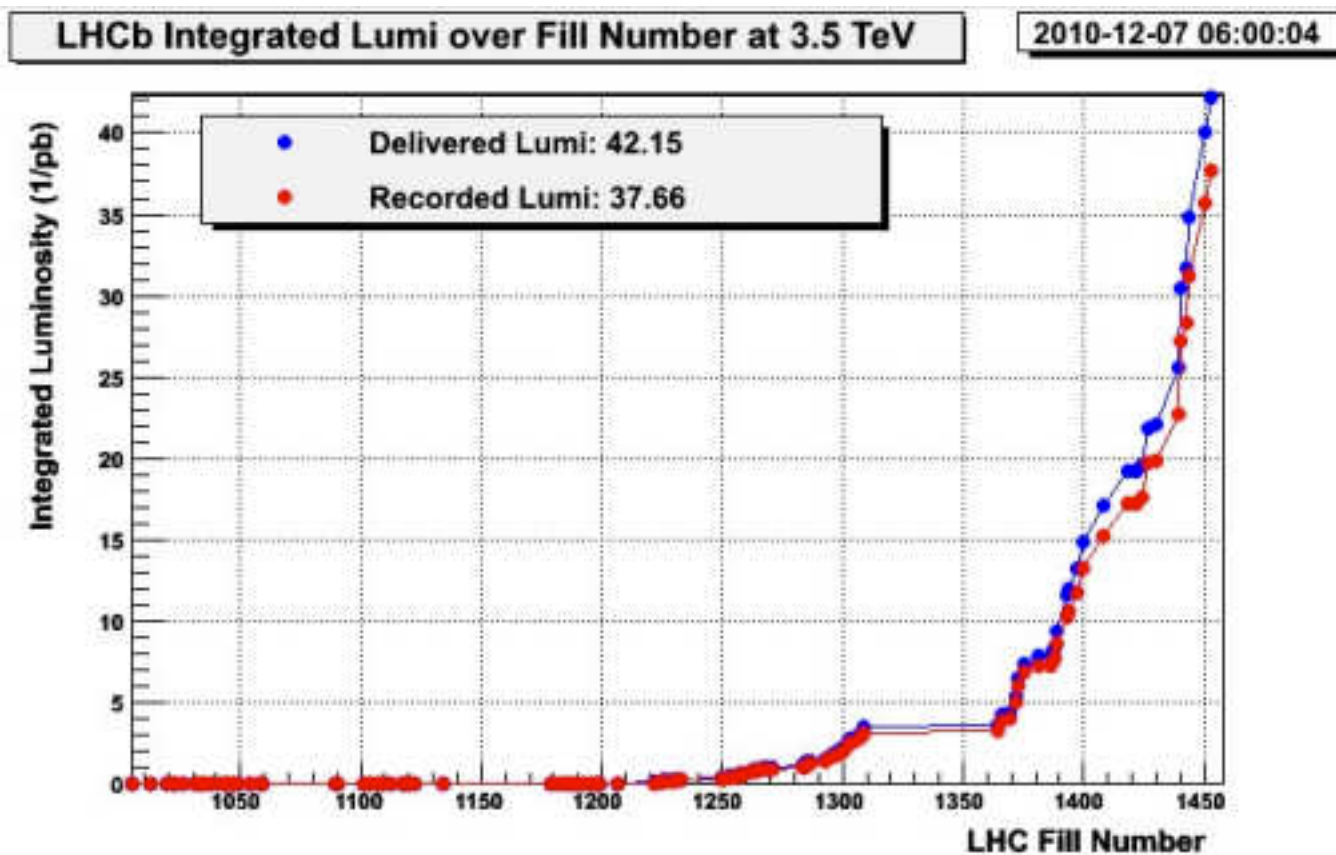
- Overlap region with Atlas/CMS ($1.9 < \eta < 2.5$)
- High rapidities unique to LHCb ($2.5 < \eta < 4.9$)

Can record low momentum muons

- Reco: $P > 3\text{GeV}$ & $P_T > 0.5\text{GeV}$
- Trigger: $M_{\mu\mu} > 2.5\text{GeV}$ & $\sum P_T > 1.5\text{GeV}$
- Exclusive trigger stream: $M_{\mu\mu} > 1\text{GeV}$



LHCb: A **forward** spectrometer



2010: 37.7 pb^{-1} of data on tape,
16.5 pb^{-1} used thus far for electroweak measurements
2011: Hope for 1-2 fb^{-1} of data

Direct Measurements

- Direct measurement of beam parameters - shape, current etc.
- Two methods employed
 - Van der Meer scan
 - Beam profiling via beam gas interactions
- See talk of Vladislav Balagura in this afternoons session for details

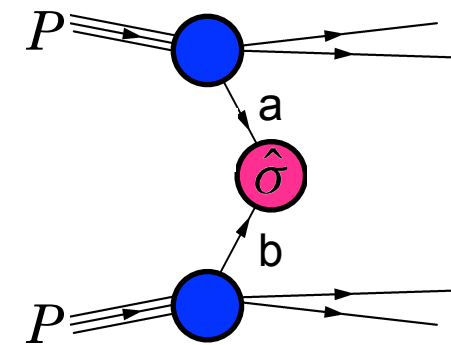
Indirect Measurements

- Measure the event rate of some theoretically well known process
- Precision determined by:
 - The uncertainty on the cross-section prediction
 - Experimental uncertainties (efficiencies etc.)
- Two processes identified at LHCb for this purpose
 - W & Z production
 - Dimuon production via two photon fusion

W & Z production at LHCb

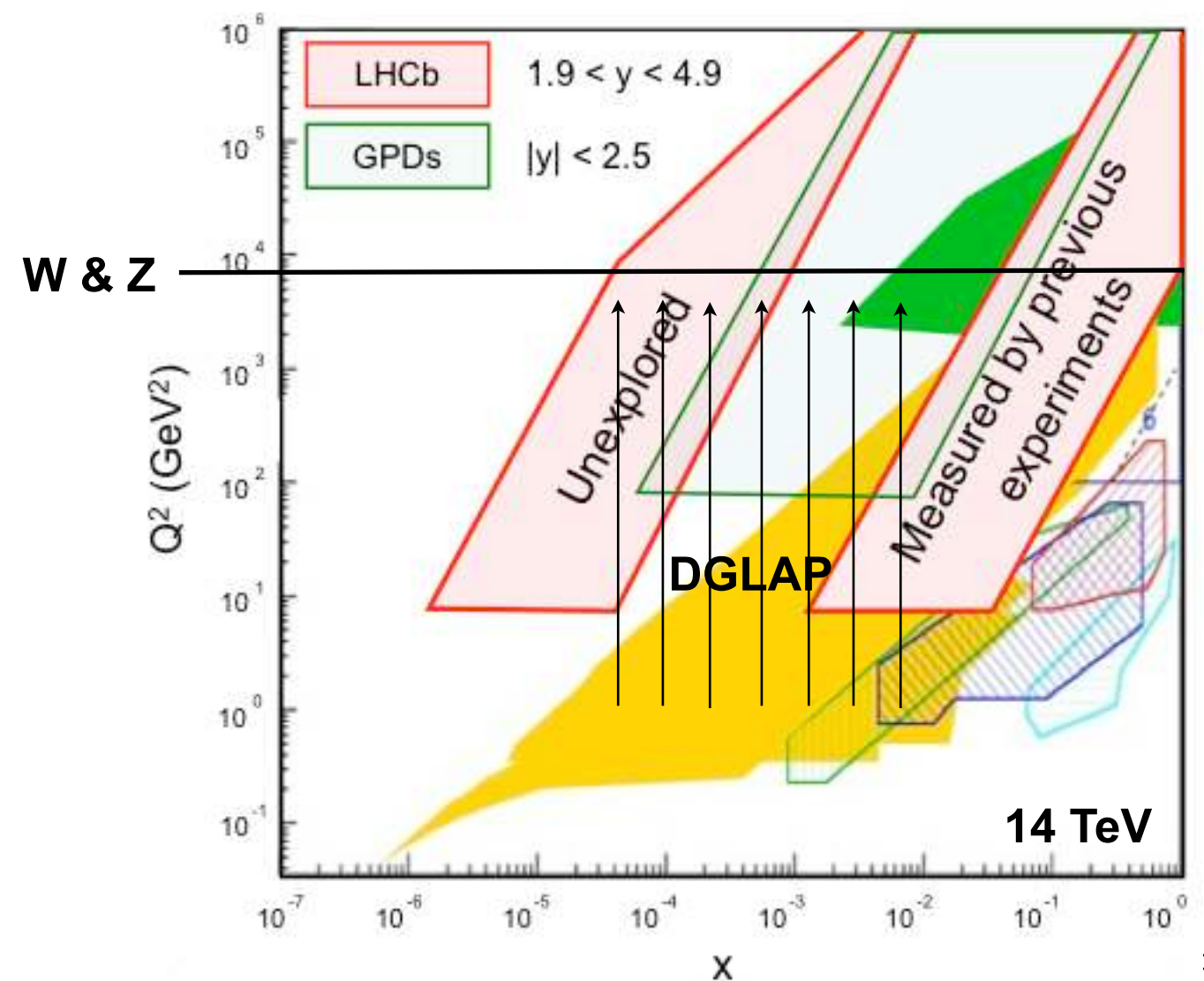
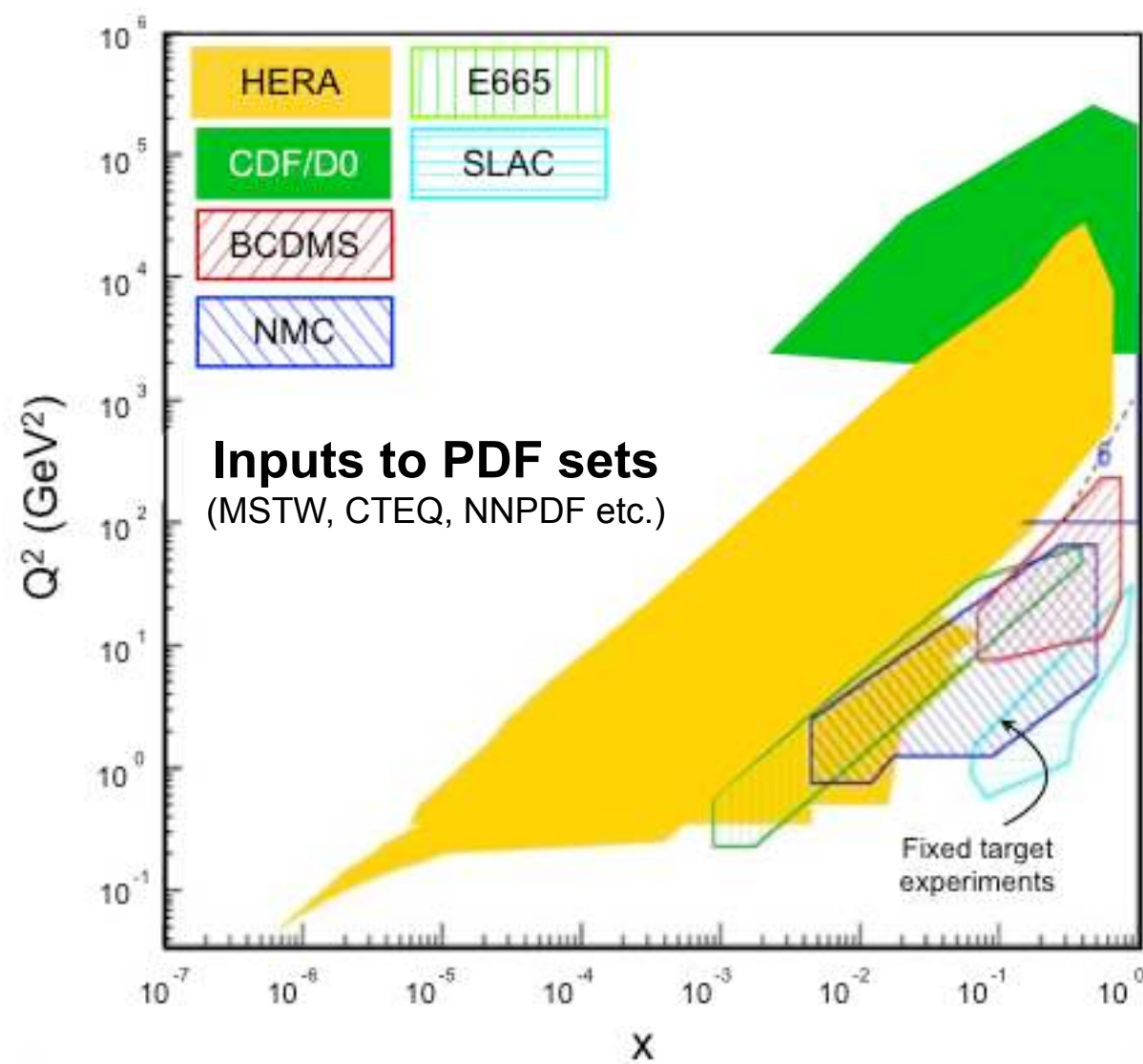
Cross-section calculation must be factorised:

$$\sigma_{pp \rightarrow Z} = \int dx_a dx_b f_{a/p_1}(x_a, Q^2) f_{b/p_2}(x_b, Q^2) \hat{\sigma}_{ab \rightarrow Z}$$



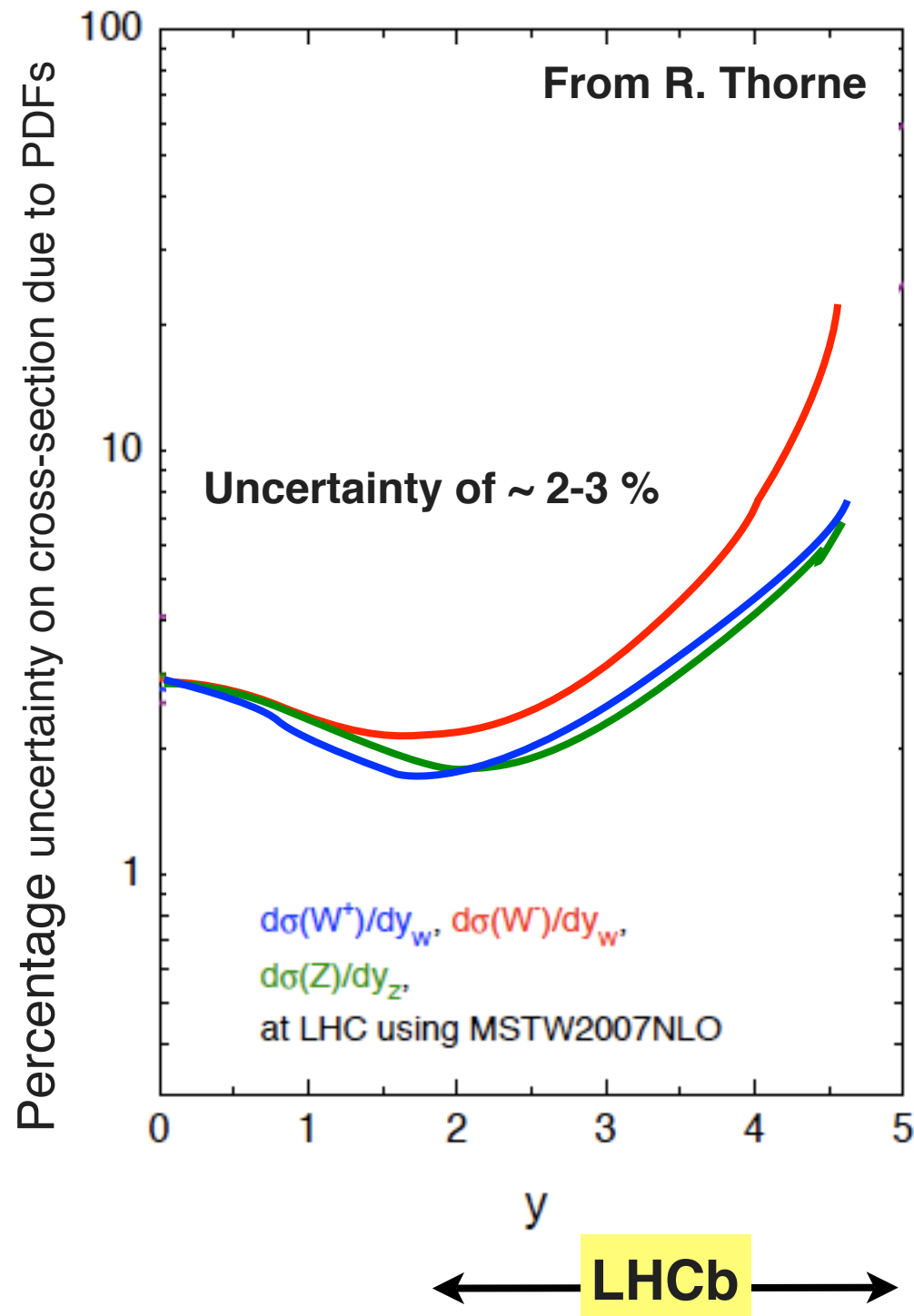
PDFs: parameterised using data from previous experiments (HERA, Tevatron, fixed target)

NNLO: accurate to $\sim 1\%$ for W & Z

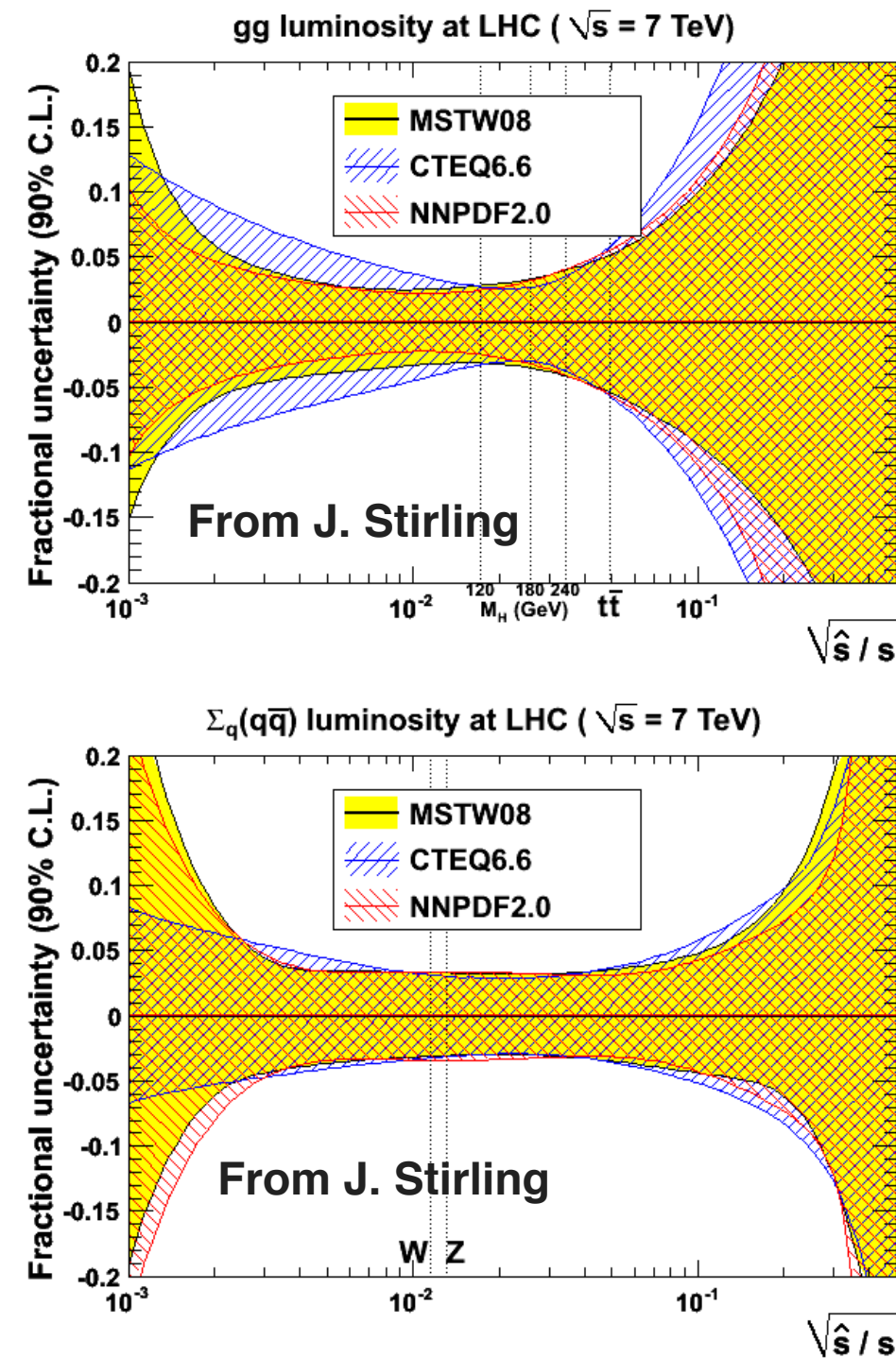


PDF uncertainties at $Q^2 \sim M_Z^2$ at the LHC

PDF uncertainty from MSTW



Comparison with other PDF sets



Overall uncertainty $\sim 4-5\%$

Z cross-section measurement at LHCb

Trigger:

Single μ , $p_T > 10$ GeV

Muon:

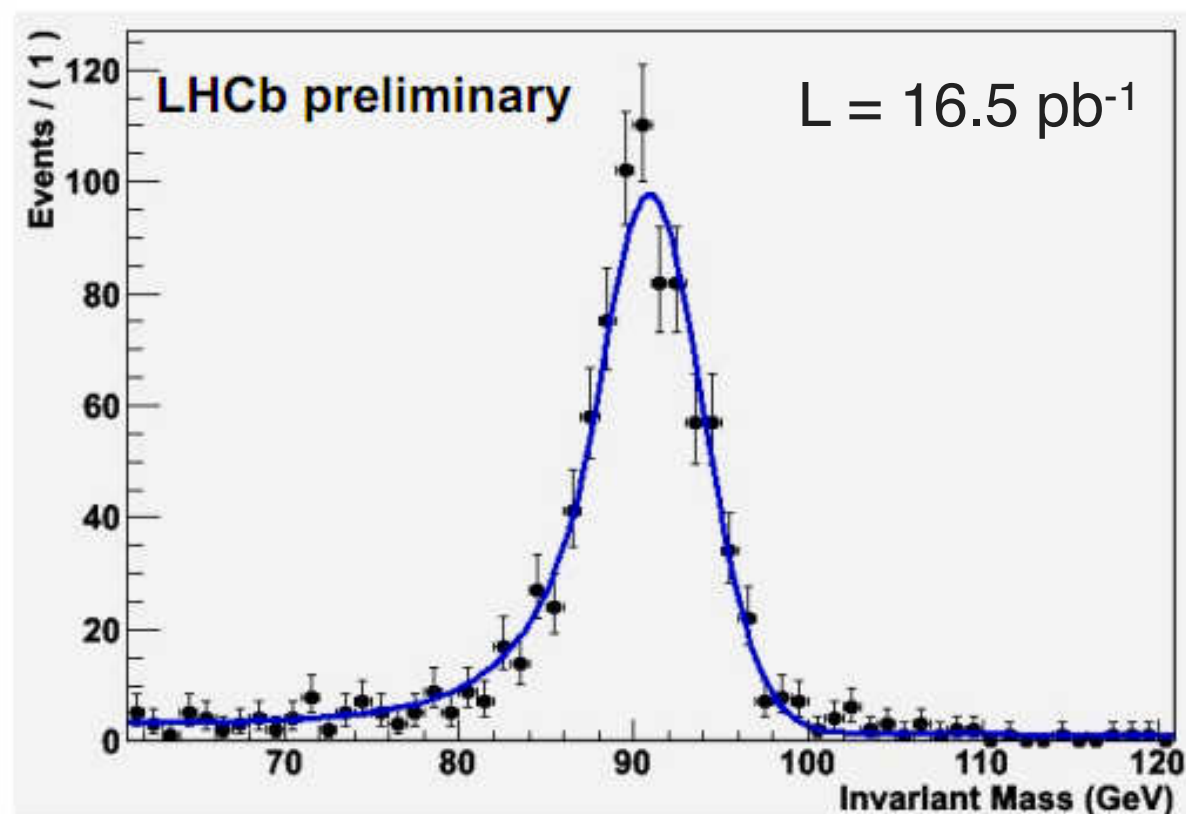
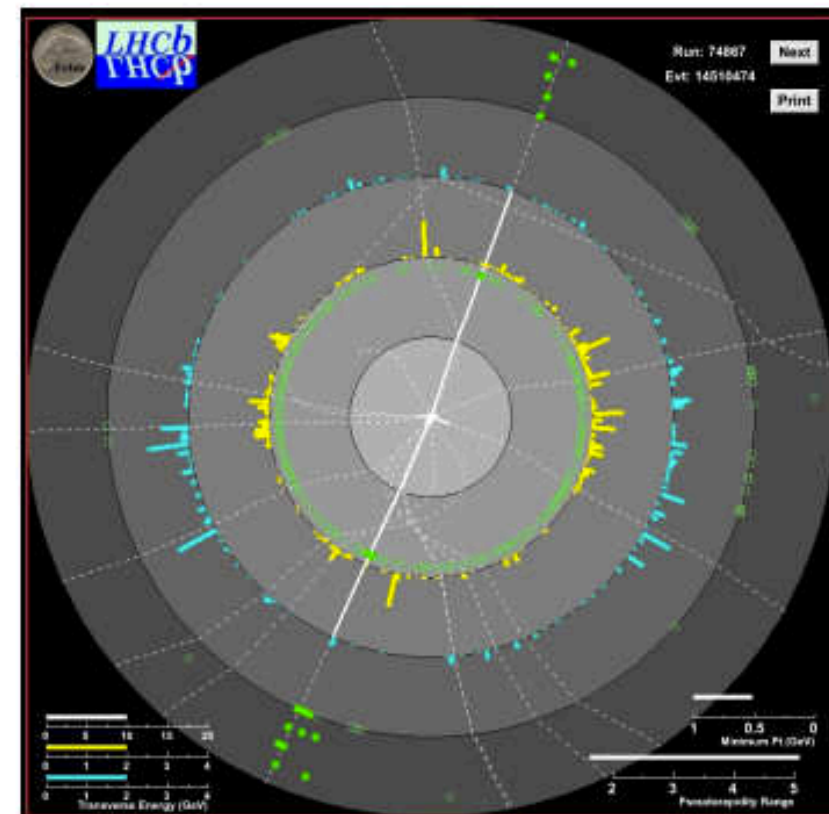
Good track quality (σ_p/p , χ^2 probability)

$p_T > 20$ GeV

$2.0 < \eta < 4.5$

Z:

$81 < m(\mu\mu) < 101$ GeV



$$N_Z = 833 \text{ (16.5 pb}^{-1}\text{)}$$

Backgrounds:

Z \rightarrow tautau (~ 0.2)

Heavy flavour (~ 1)

Hadron mis-id (< 0.03)

$$N_{\text{bkg}} = 1.2 \pm 1.2$$

W cross-section measurement at LHCb

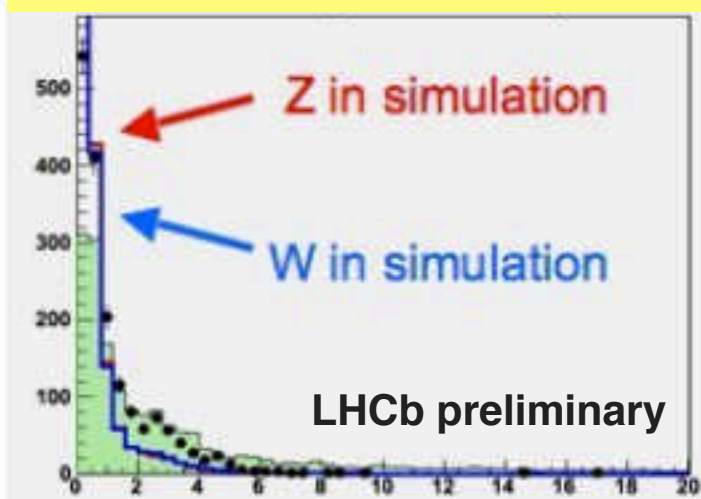
Data driven efficiency and purity determination

$$W(\text{sim}) = Z(\text{sim})$$

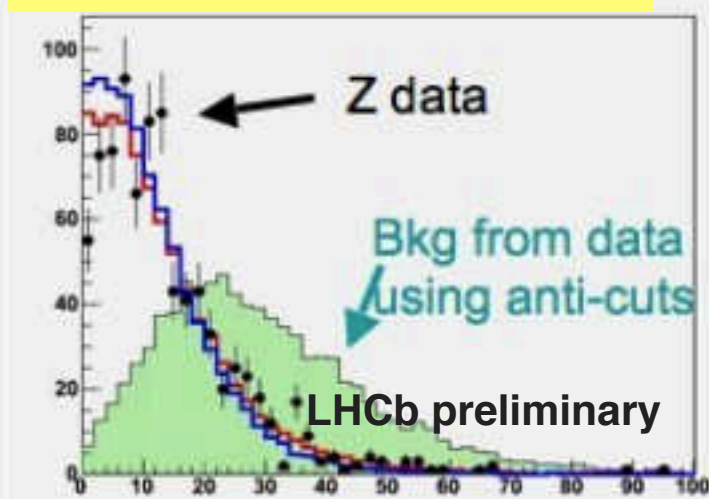
$$Z(\text{sim}) \sim Z(\text{data})$$

$$\text{Background}(\text{data}) \neq Z(\text{data})$$

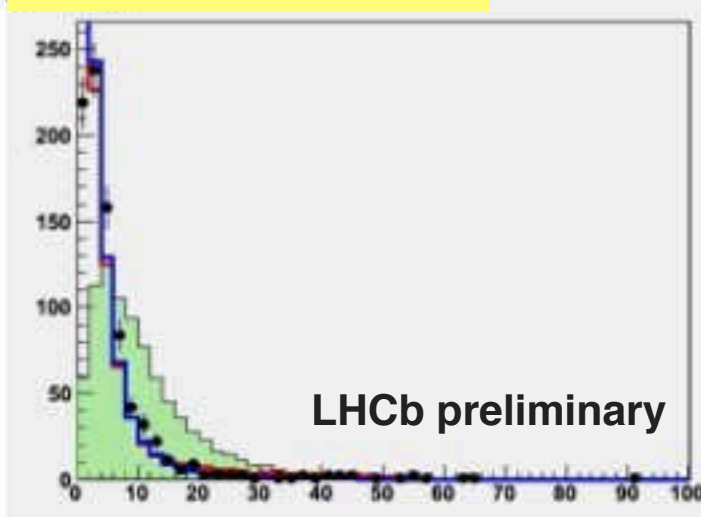
Muon impact parameter significance



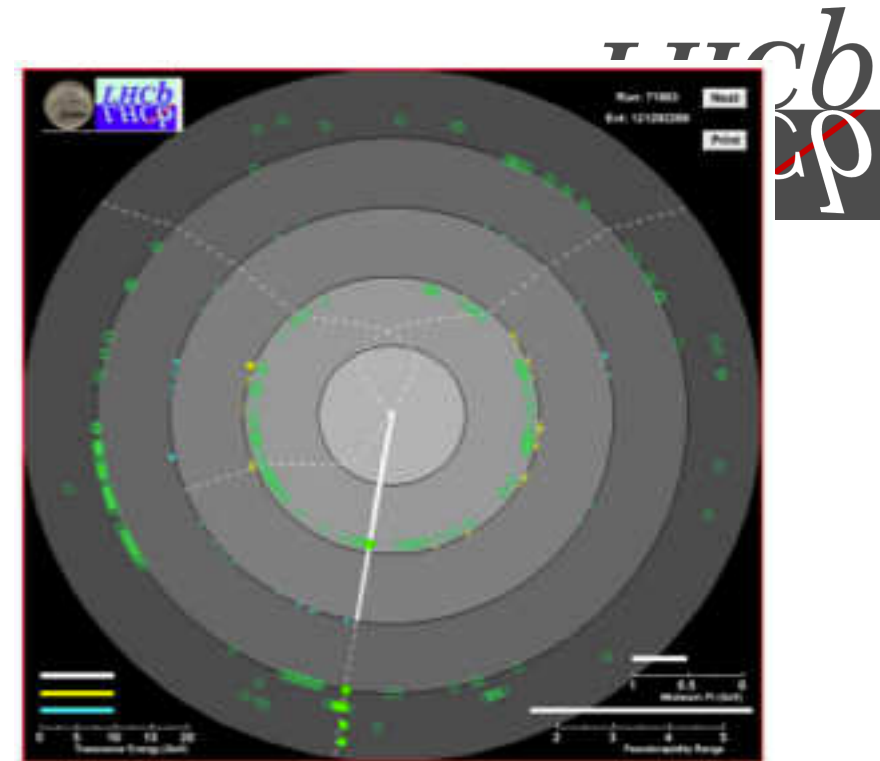
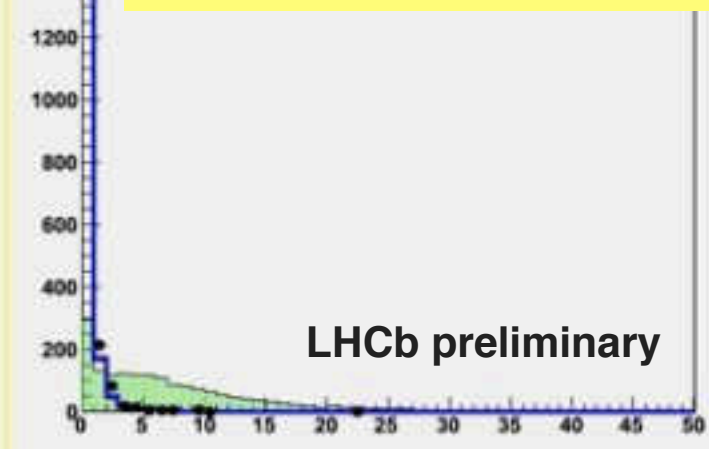
Invariant mass of rest of event



Pt sum of rest of event



Pt sum of particles in cone around muon (R=0.5)



Data derived:

- cuts
- efficiency (sel eff = 55 ± 1 %)
- purity

Cuts applied:

- Muon IPS < 2
- Event mass < 20 GeV
- Event $\sum Pt$ < 10 GeV
- Cone $\sum Pt$ < 2 GeV

Determination of efficiencies: trigger

$$\epsilon_Z = A_Z \epsilon_Z^{trig} \epsilon_Z^{track} \epsilon_Z^{muon} \epsilon_Z^{selection}$$

Single muon trigger efficiency

- Determine from data using an offline selected Z sample and tag and probe method

Tag: muon passing single muon line

Probe: Offline identified muon

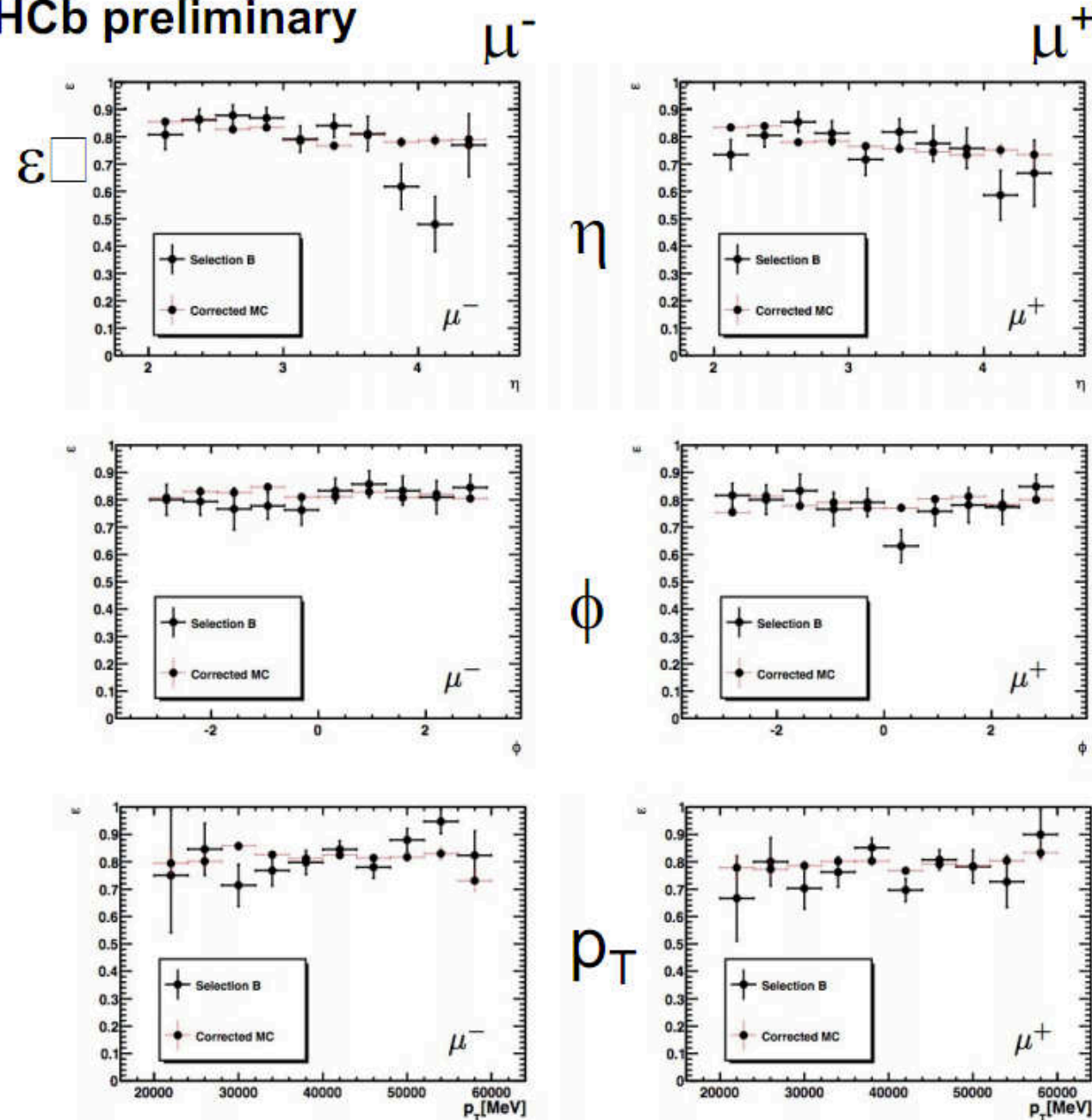
- Efficiency given by how often the probe muon passes the single muon line

Efficiency is flat in eta, phi and Pt

No evidence of charge bias

$$\text{eff} = 86 \pm 1 \%$$

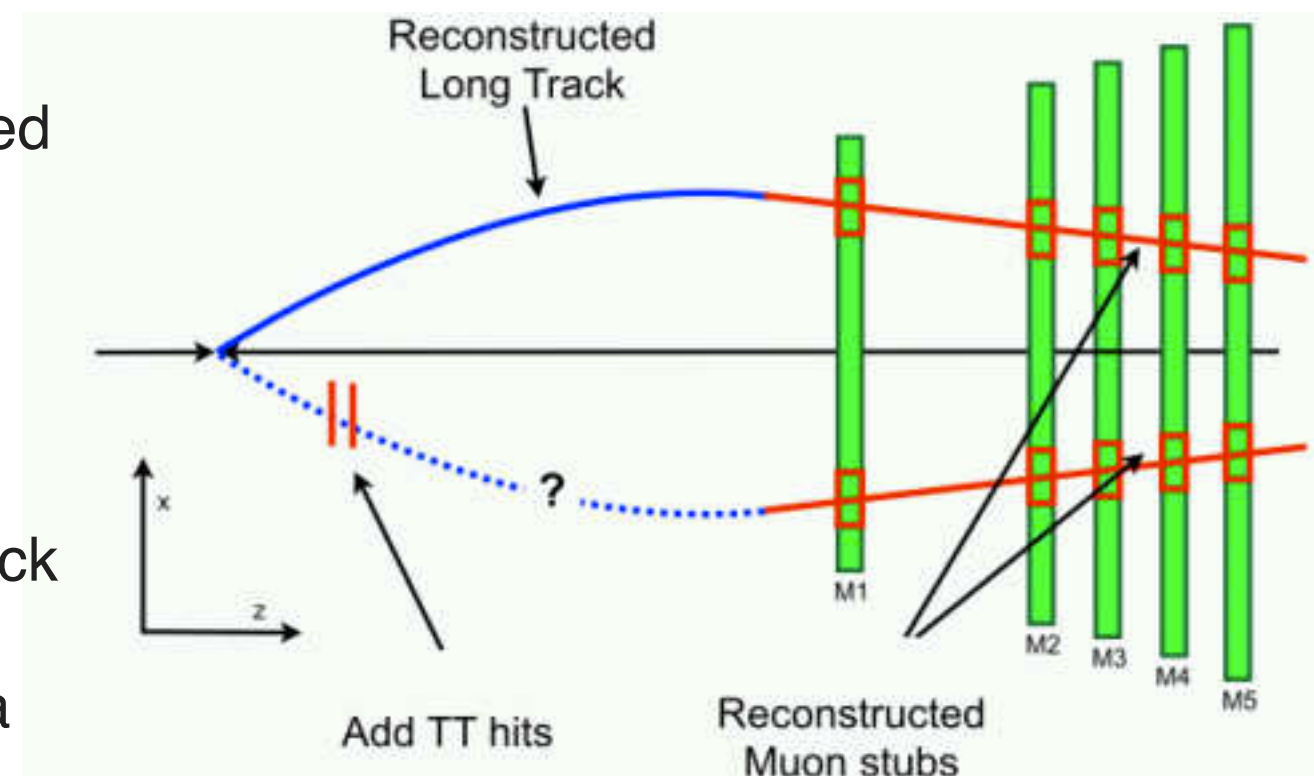
LHCb preliminary



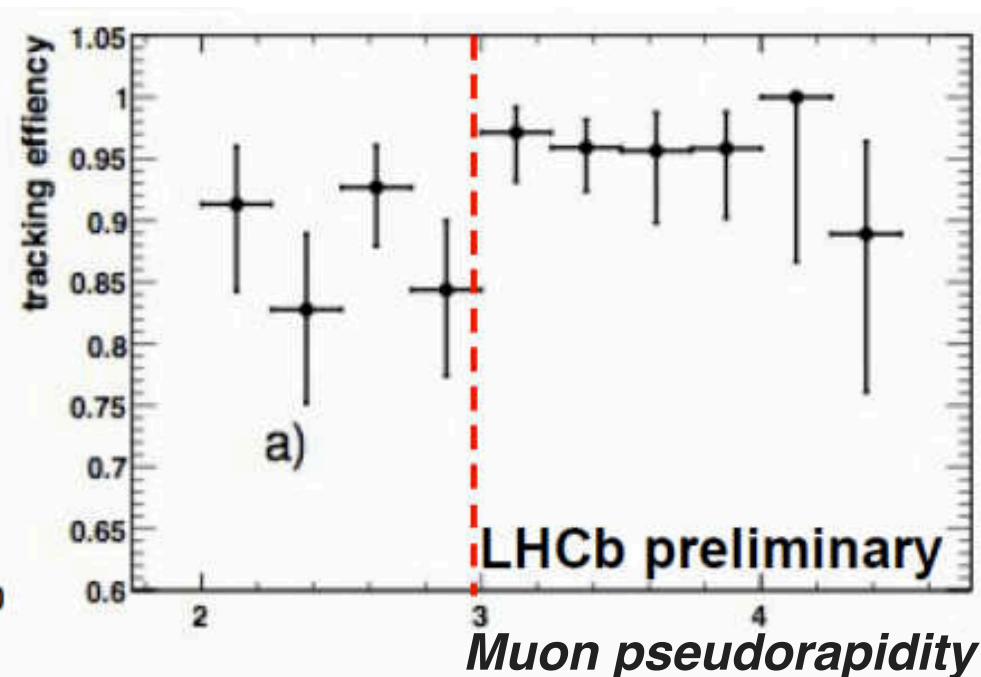
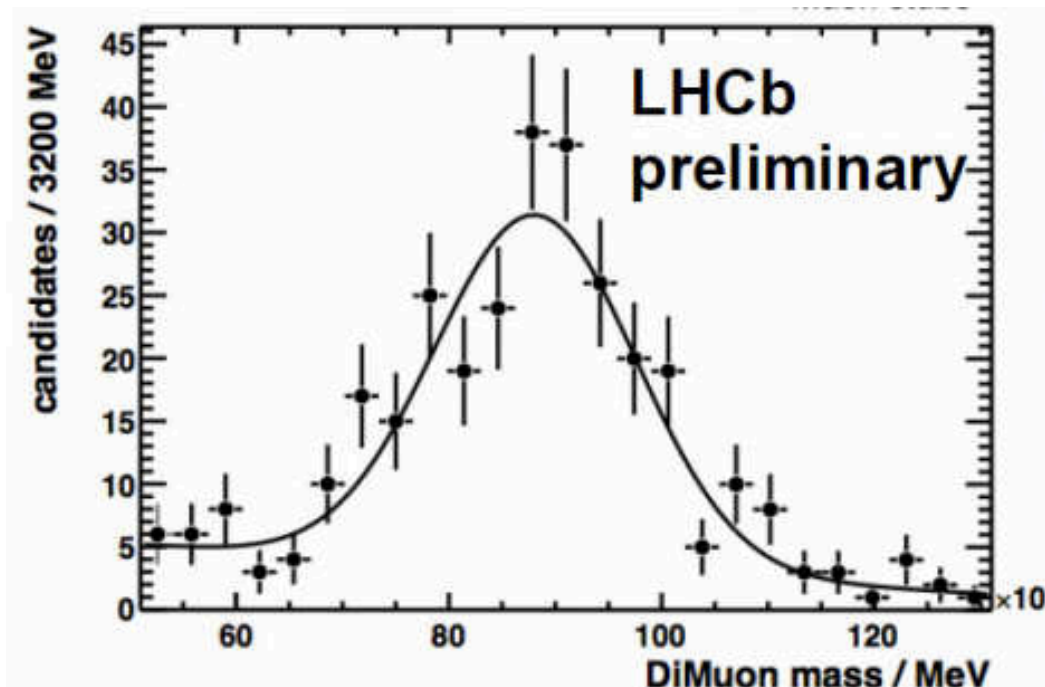
Determination of efficiencies: tracking

Single muon tracking efficiency

- Determine from data using an offline selected Z sample and tag and probe method
Tag: long track muon passing trigger
Probe: Muon stub with TT hits added
- Efficiency given by how often the probe can be matched to a reconstructed long track



Flat in P_t and ϕ , 2 regions considered in η
 No evidence of charge bias
 $\text{eff} = 93 \pm 1 \%$



Determination of efficiencies: muon id

$$\epsilon_Z = A_Z \epsilon_Z^{trig} \epsilon_Z^{track} \epsilon_Z^{muon} \epsilon_Z^{selection}$$

Single muon identification efficiency

- Determine from data using an offline selected Z sample and tag and probe method

Tag: long track muon passing trigger

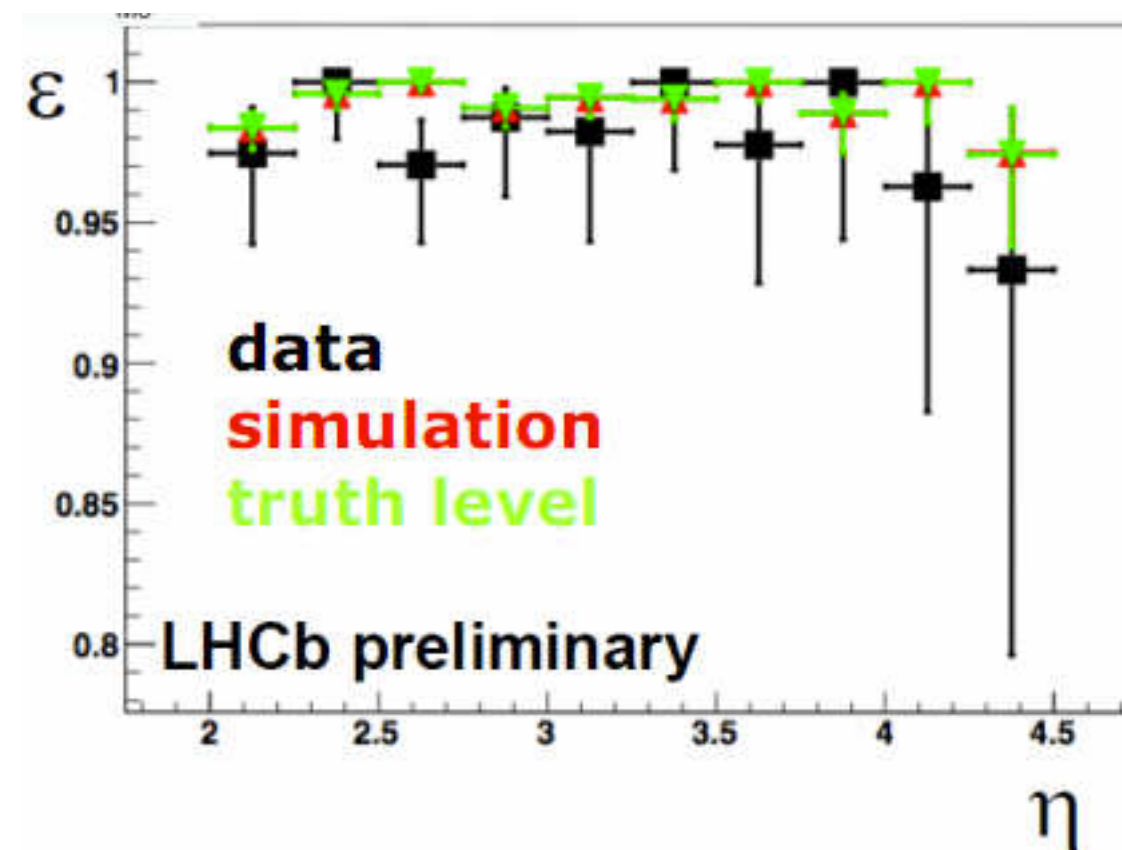
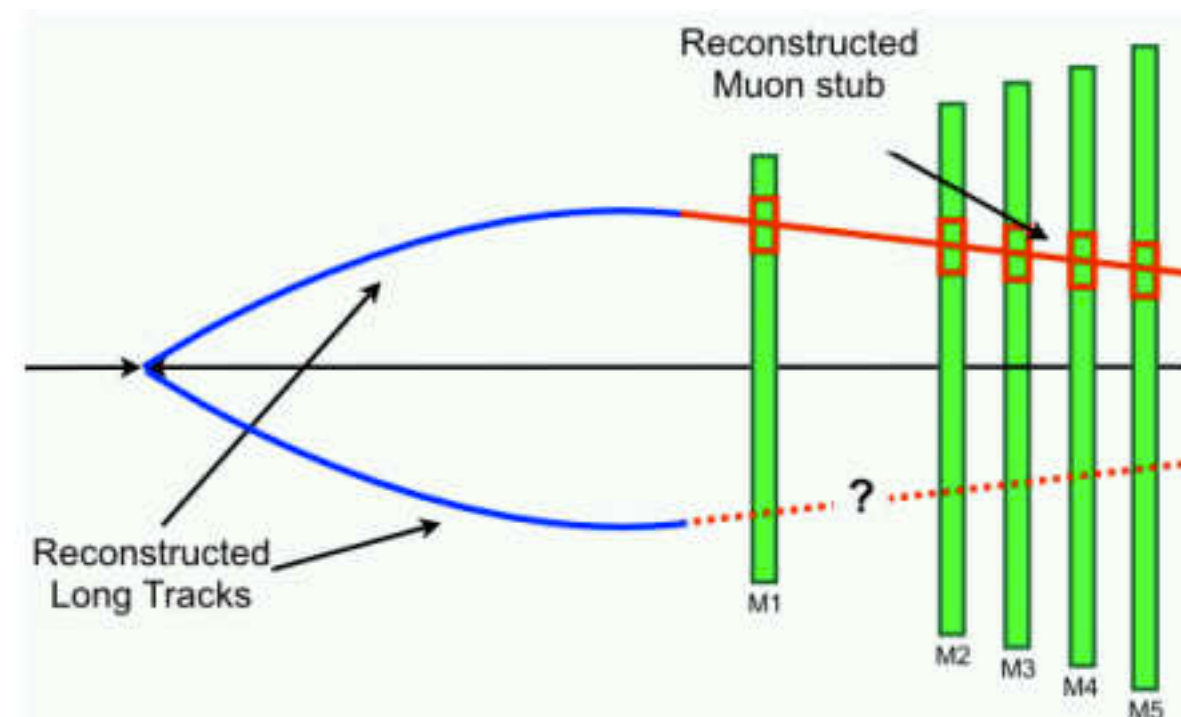
Probe: Long track

- Efficiency given by how often the probe is identified as a muon

Flat in Pt, phi and eta

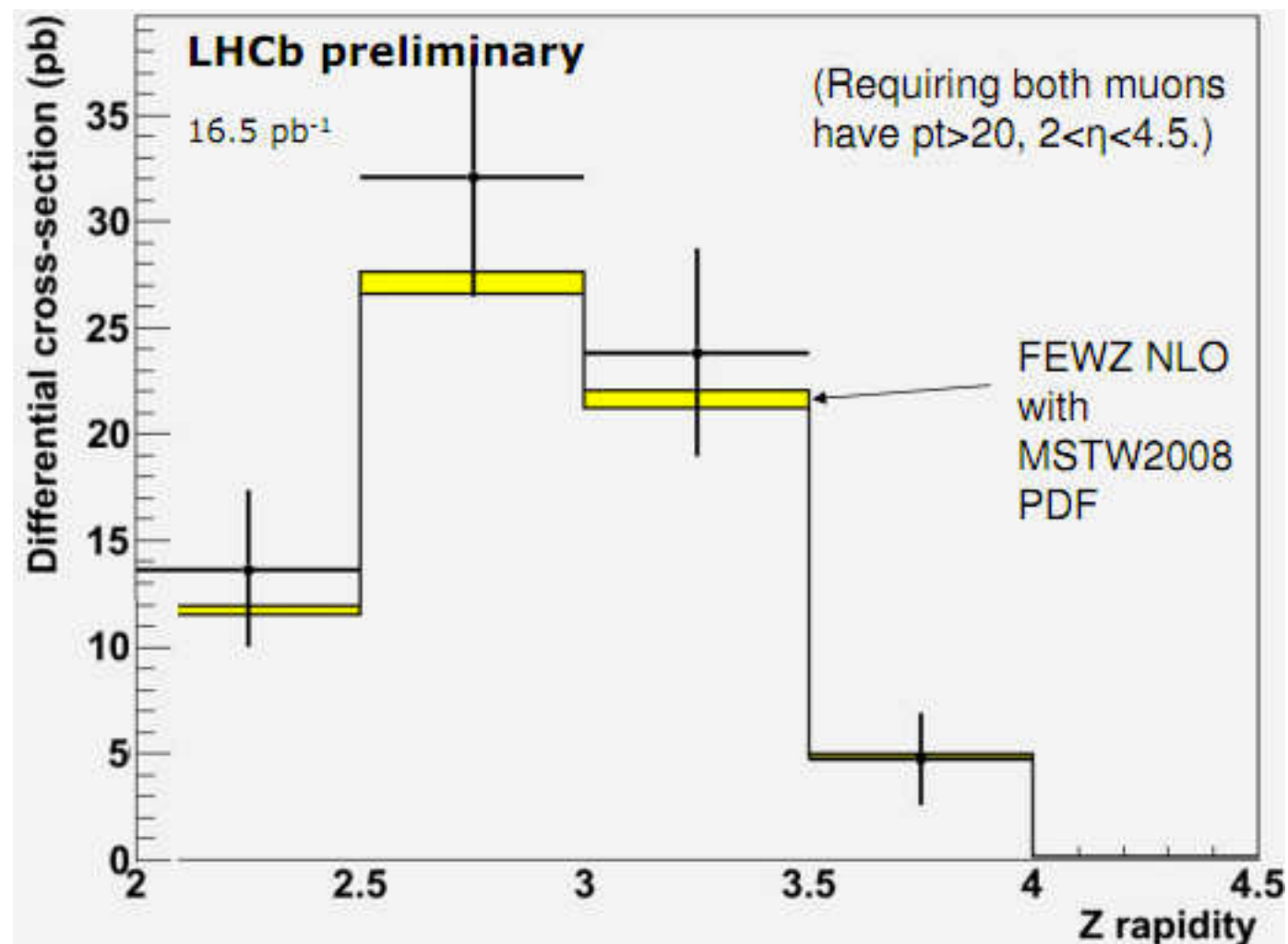
No evidence of charge bias

eff = 98.2 ± 0.5 %



Z cross-section measurement at LHCb

| | |
|---|------------------------|
| N_Z^{tot} | 833 |
| $Z \rightarrow \tau\tau$ | 0.2 ± 0.2 |
| Heavy flavours | 1 ± 1 |
| Misidentified π/K | $<< 1$ |
| N_Z^{bkg} | 1.2 ± 1.2 |
| ϵ_Z^{trig} | 0.86 ± 0.01 |
| ϵ_Z^{track} | 0.83 ± 0.03 |
| ϵ_{muon}^Z | 0.97 ± 0.01 |
| ϵ_{sel}^Z | 1. |
| A^Z | 1. |
| ϵ_Z | 0.69 ± 0.03 |
| L | $16.5 \pm 1.7 pb^{-1}$ |
| $\sigma_Z(2. < \eta_1, \eta_2 < 4.5, 81 < m_Z < 101)$ | $73 \pm 4 \pm 7 pb.$ |



W cross-section measurement at LHCb

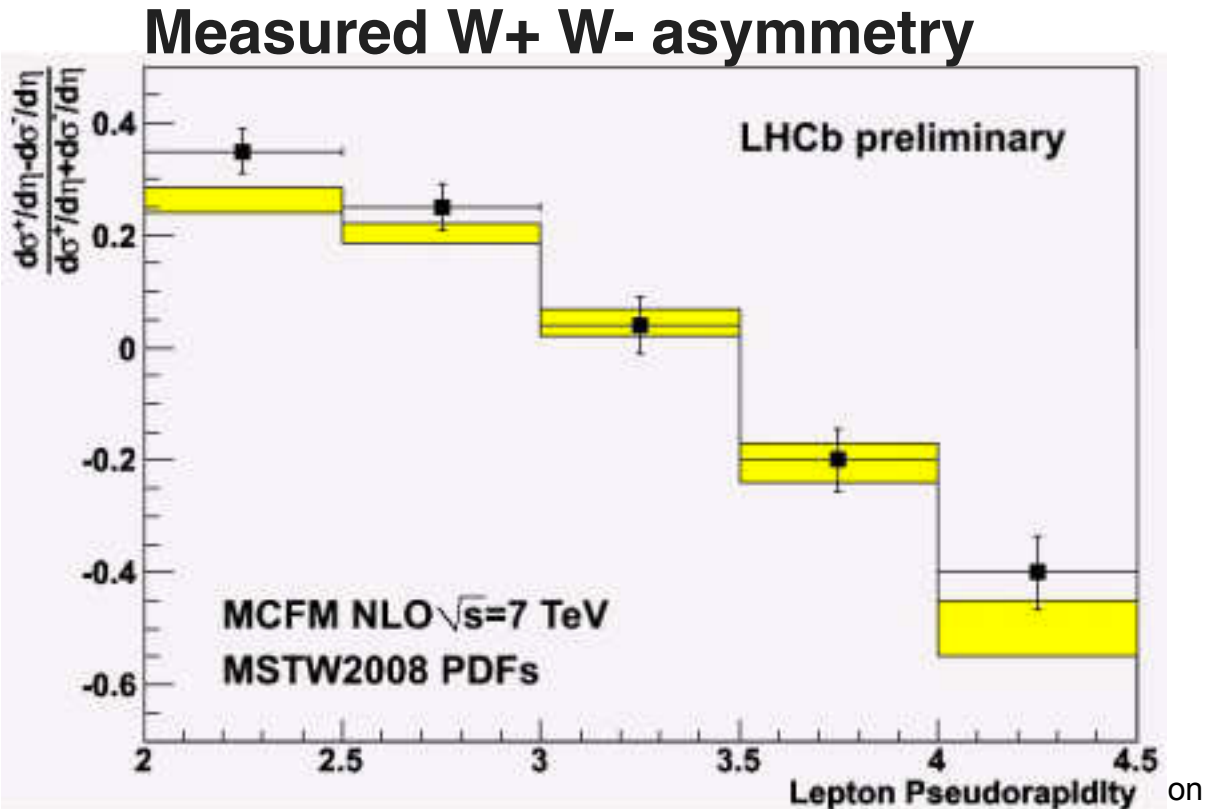
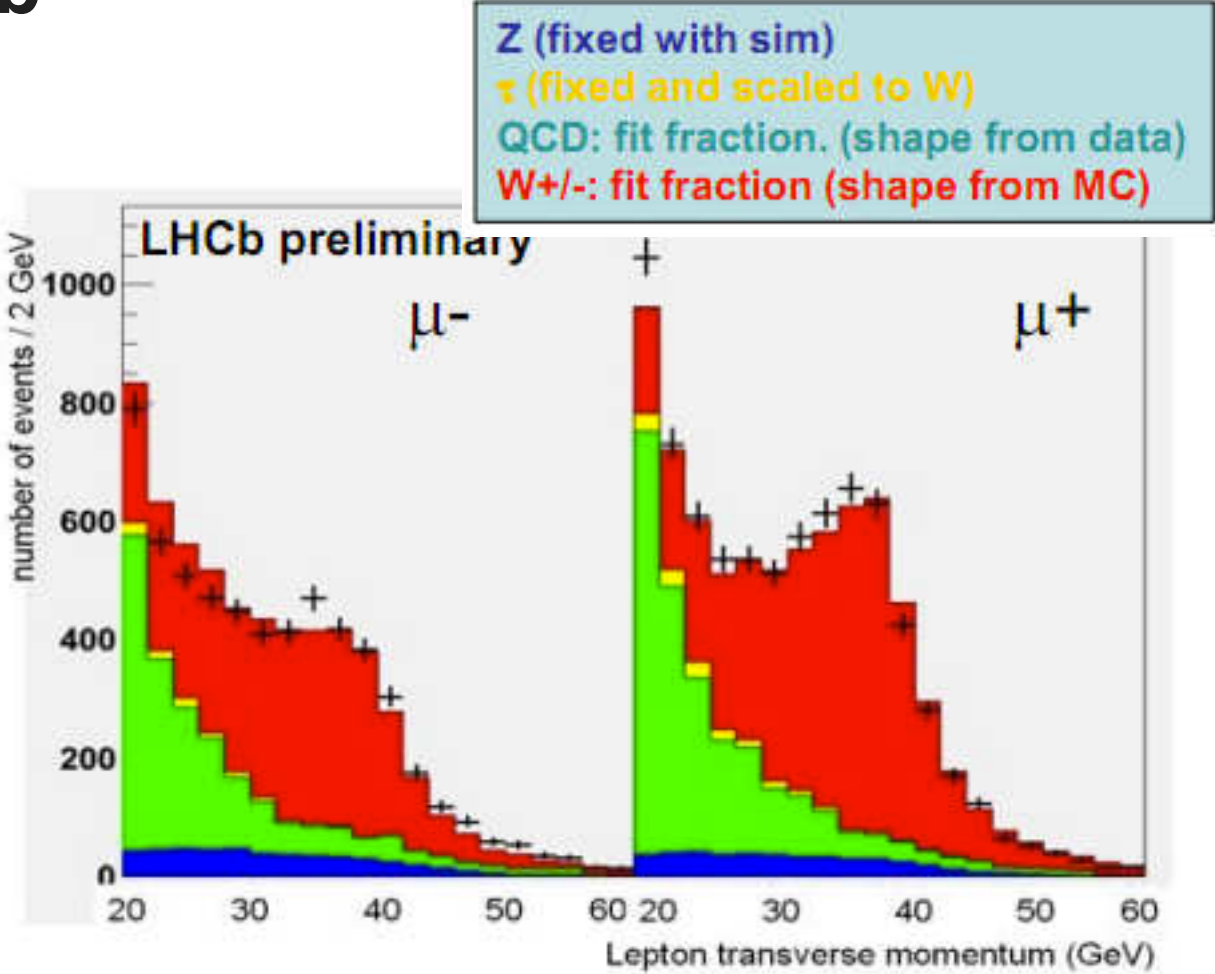
Fit muon Pt spectrum in data to expected shapes for signal and background and extract number of background events

$$N_{\text{bkg}+} = 2194 \pm 150$$

$$N_{\text{bkg}-} = 1654 \pm 150$$

Trigger, tracking and muon-id efficiencies from Z sample and tag and probe

| | W+ | W- |
|-----------------------------|----------------------------------|--------------------------------|
| N_W^{tot} | 7624 | 5732 |
| $W \rightarrow \tau \nu$ | 151 | 90 |
| $Z \rightarrow \tau \tau$ | 2 | 2 |
| $Z \rightarrow \mu \mu$ | 460 | 506 |
| QCD | 2194 ± 150 | 1654 ± 150 |
| N_W | 4817 ± 165 | 3480 ± 161 |
| ϵ_{trig}^W | 0.725 ± 0.03 | |
| $\epsilon_{\text{track}}^W$ | 0.73 ± 0.03 | 0.78 ± 0.03 |
| ϵ_{muon}^W | 0.982 ± 0.005 | |
| ϵ_{sel}^W | 0.55 ± 0.01 | |
| A^W | 1 | 1 |
| ϵ_W | 0.29 ± 0.01 | 0.31 ± 0.01 |
| N_W^{tot} | 16610 ± 800 | 11226 ± 650 |
| L | $16.5 \pm 1.7 \text{ pb}^{-1}$ | $16.5 \pm 1.7 \text{ pb}^{-1}$ |
| $\sigma_W(2.0 < y < 4.5)$ | $1007 \pm 48 \pm 100 \text{ pb}$ | $682 \pm 40 \pm 68 \text{ pb}$ |

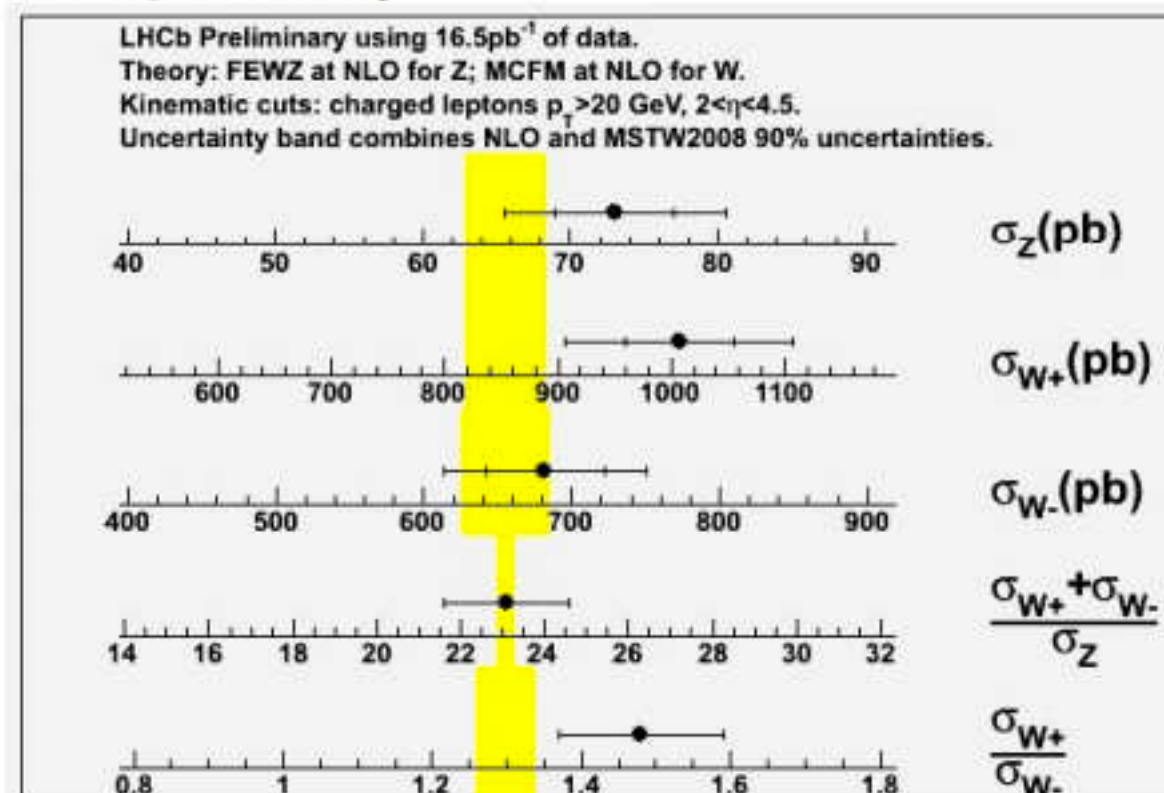


Summary of W & Z measurements

With 16.5 pb⁻¹ we see

- 9500 W's and 833 Z's
- Cross-sections and ratios have been measured and compared to NLO predictions
- This corresponds to ~ half of the 2010 data set.
- Using the Z's alone, a luminosity measurement with an uncertainty of ~ 5 % is possible

LHCb preliminary

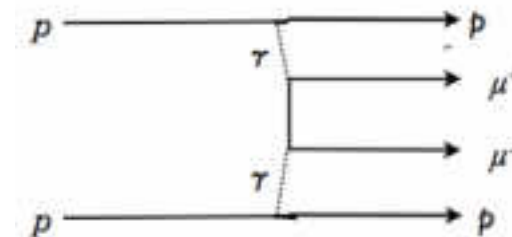


Exclusive particle production at LHCb



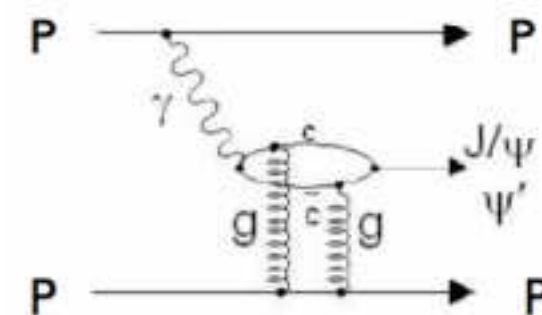
1. Dimuons from photon fusion

- Produced via diphoton fusion
- EM process: uncertainty on CS prediction $< 1\%$
 - Ideal for measuring luminosity
- Modeled by the LPAIR generator
(A.G. Shamov and V.I. Telnov NIM A 494 (2002) 51)



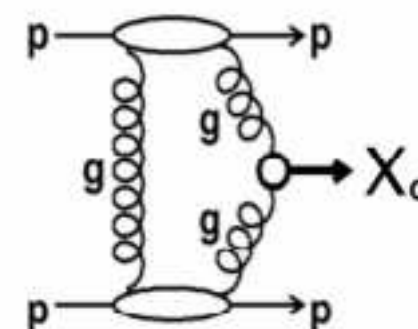
2. Exclusive JPsi, Psi' (-> mu mu)

- Produced by photon pomeron fusion
- Modeled by the Starlight generator
(S.R. Klein and J. Nystrand, Phys. Rev. Lett. 92 (2004) 14003)

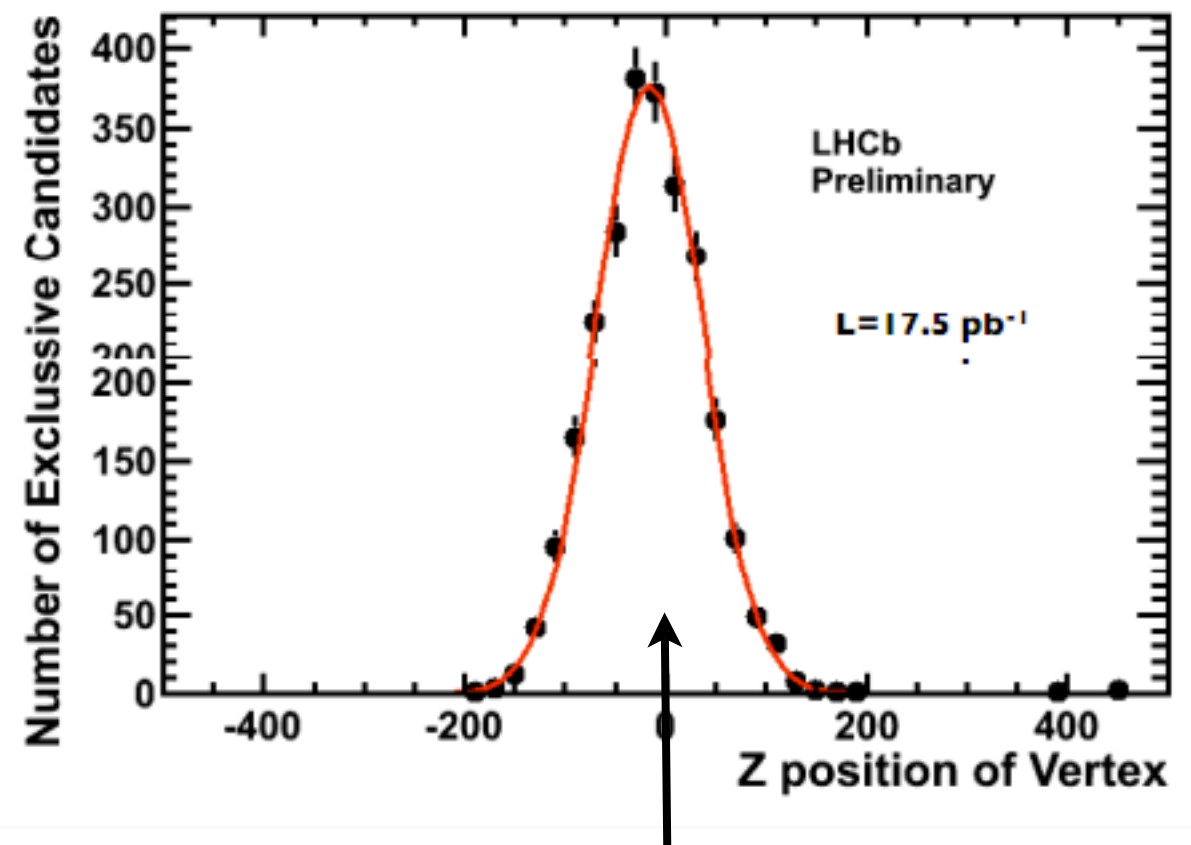
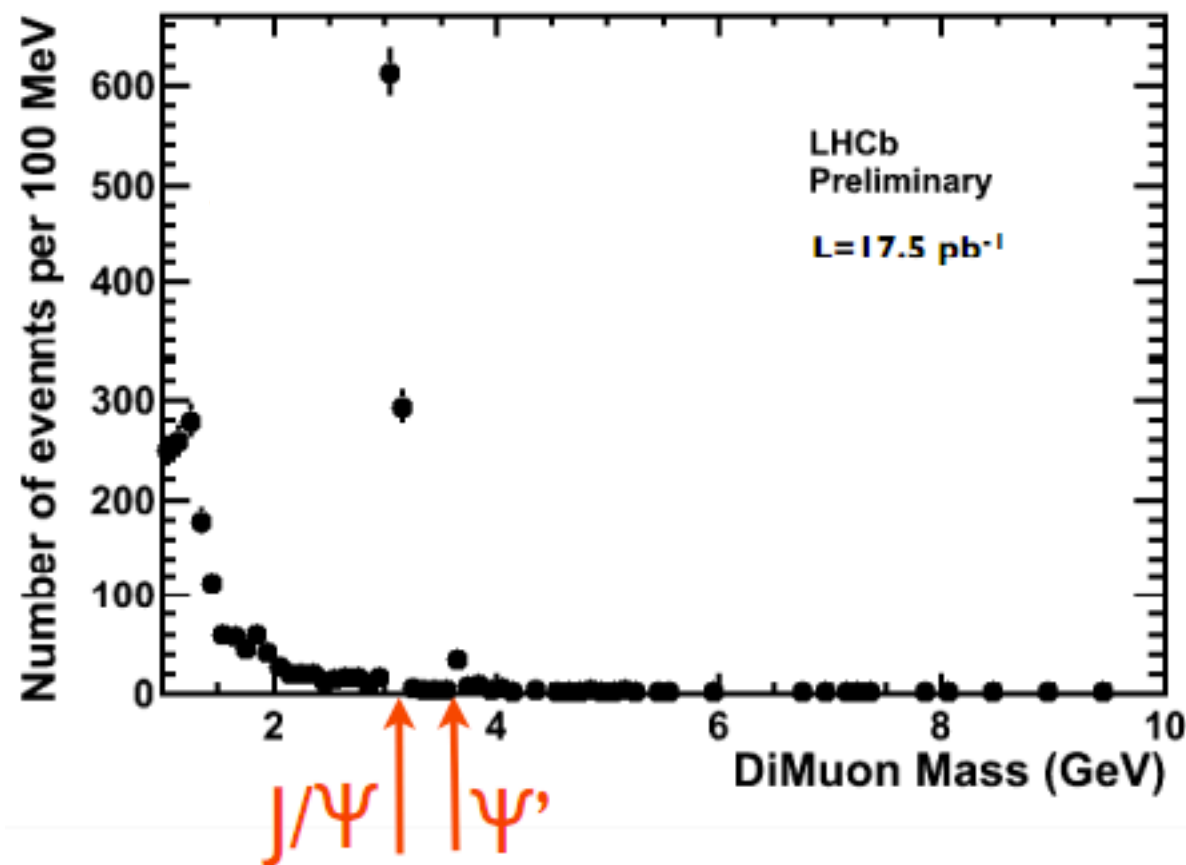


3. Exclusive ChiC (-> mu mu + gamma)

- Produced by double pomeron exchange
- Modeled by the SuperChiC generator
(L.A. Harland-Lang, V.A. Khoze, M.G. Ryskin, W.J. Stirling
arXiv:0909.4748 [hep-ph])



Full exclusive dimuon spectrum (17.5 pb⁻¹)



Candidates compatible with beam-beam interactions

Trigger requirements:

- Just two muons
- Distance of closest approach < 0.15 mm
- Dimuon Mass > 1 GeV
- Dimuon Pt < 0.9 GeV
- SPD multiplicity < 20

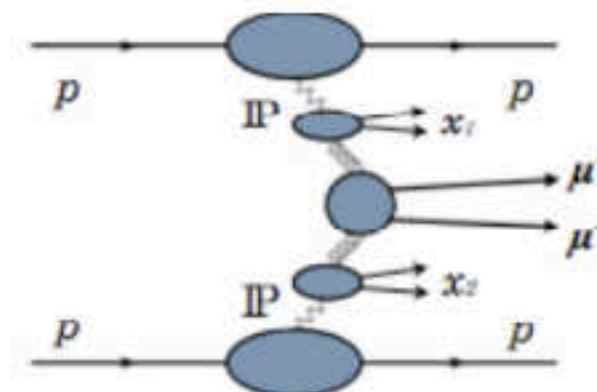
Additional offline requirements:

- No additional tracks in the vertex detector
- SPD multiplicity < 5 offline

Backgrounds for exclusive dimuons from photon fusion

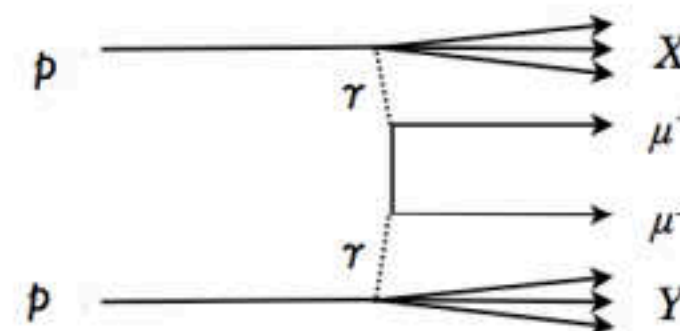
Dimuons from Double Pomeron Exchange (DPE)

Generated with Pomwig (Does not contain Multi Parton Interactions)
Pythia used to estimate effect of MPI (Pomwig predictions scaled by 0.3)
H1 pomeron PDFs (06 and 97 NLO) used



Dimuons from Inelastic diphoton fusion

One or both protons dissociate during interaction
Generated with LPAIR
A.Suri and D.R.Yennie Proton PDFs used



Mis-Id from Min Bias Data

Min Bias events dominated by pions and kaons
Apply all cuts except requiring that the track is a muon
Scale distribution by probability for pions/kaons to be identified as muons
(Mis-Id Probability as a function of Particle P determined in separate study)

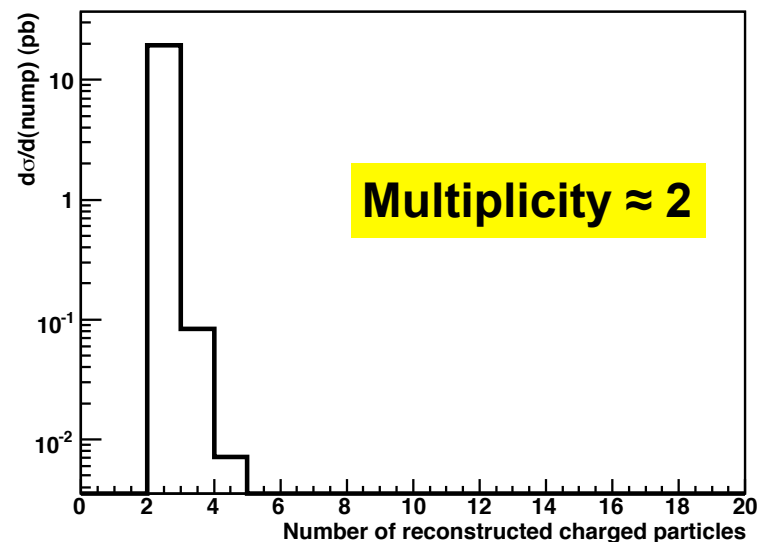
**Negligible
contribution**



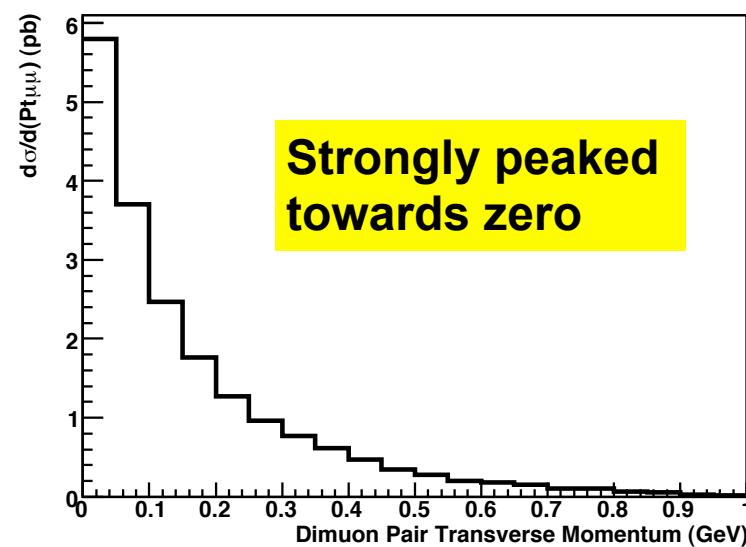
Discriminating variables for background suppression (MC)

Signal

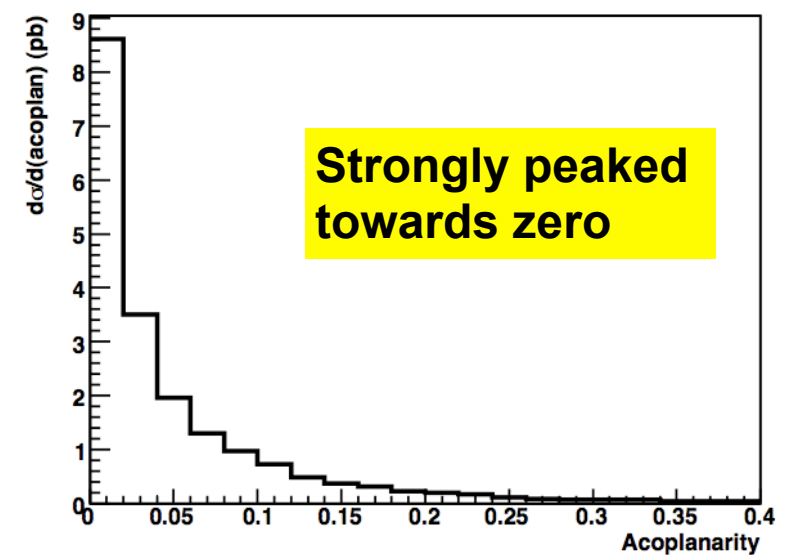
Number of tracks



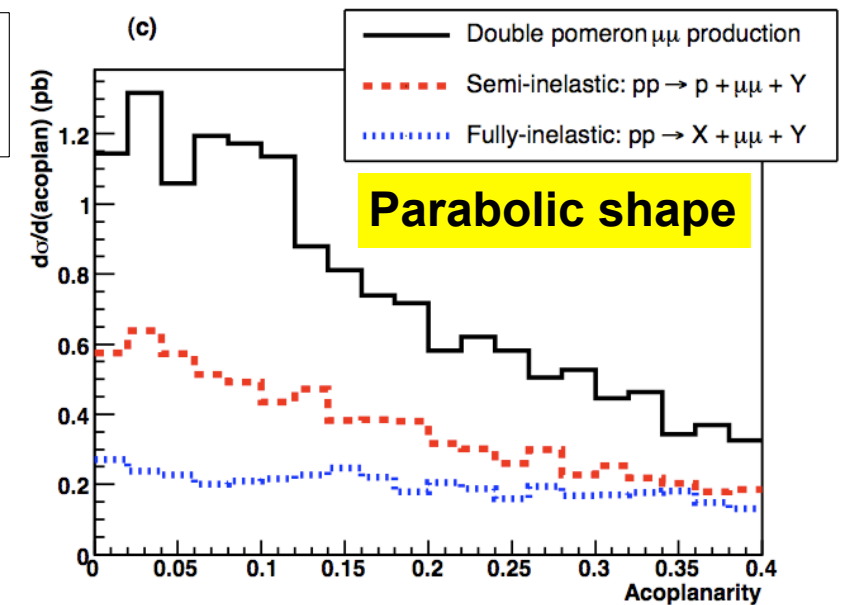
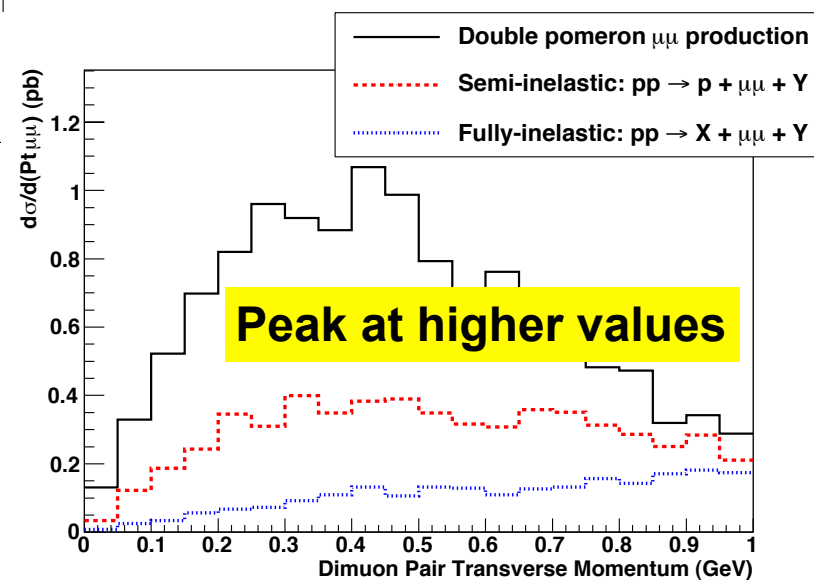
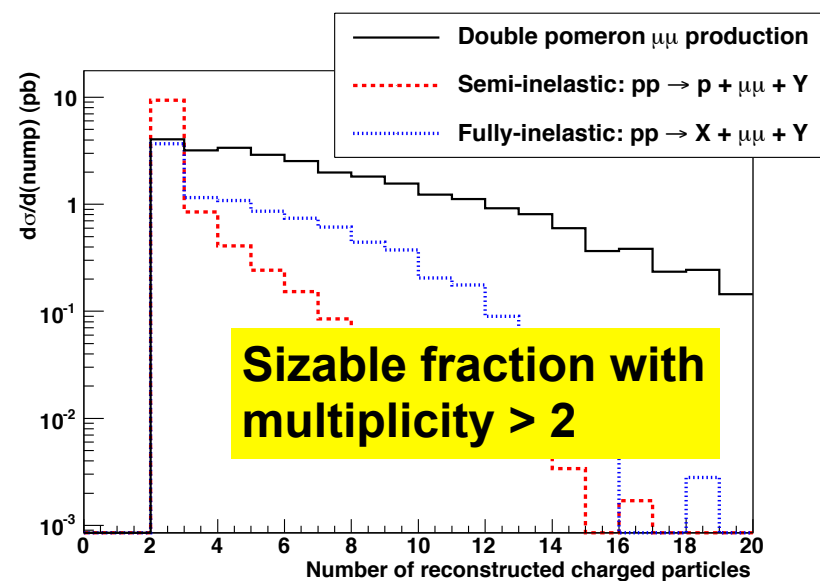
Dimuon Pt



Dimuon acoplanarity

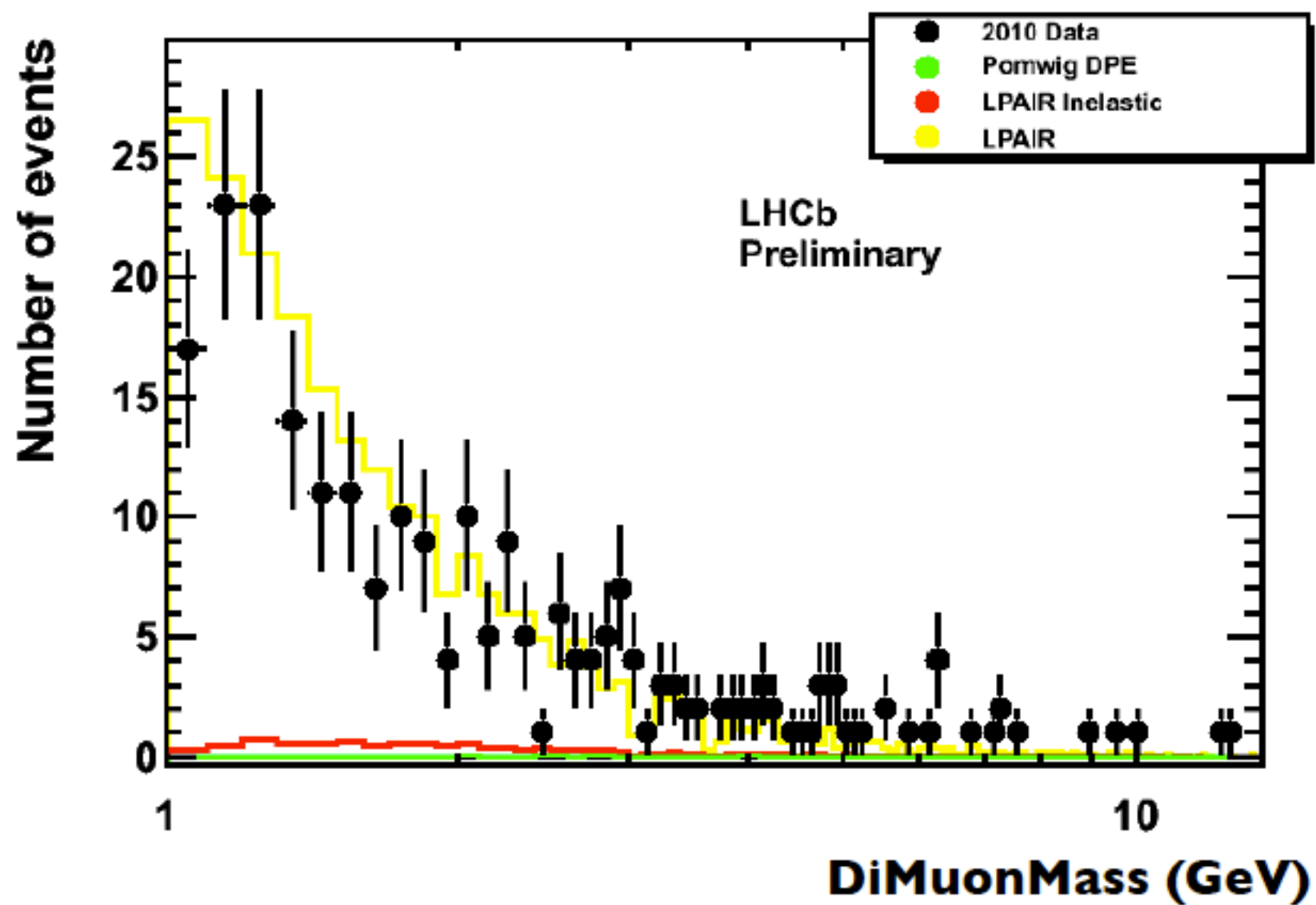


Inelastic & DPE



Comparison with Monte-Carlo

Track multiplicity = 2 & Acoplanarity < 0.1



Luminosity measurements with W & Z events

- W & Z cross-sections predicted with $\sim 4\%$ uncertainty
- Very clean Z sample available with reasonable statistics (833 events in 16.5 pb^{-1})
- Efficiencies well understood from data
- Full 2010 data-set will enable a luminosity measurement with $\sim 5\%$ uncertainty
- W events could also be used. 10 times more stats but lower purity

Luminosity measurements with exclusive dimuons from photon fusion

- Cross-sections predicted with $< 1\%$ uncertainty
- 250 candidate events selected in 17.5 pb^{-1}
- Purities seem high (more work needed)
- Work on understanding efficiencies has only just begun
- Exclusive J Ψ , Ψ' and χ C events have also been isolated and compared to MC